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CALIFORNIA FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE - U. S. DEPARTMENT OF AGRICULTURE
in cooperation with
DIVISION OF FORESTRY
DEPARTMENT OF NATURAL RESOURCES
STATE OF CALIFORNIA

San Dimas Experimental Forest is a 17,000 acre research laboratory located in the San Gabriel mountains of southern California, maintained by the Forest Service, U. S. Department of Agriculture in cooperation with the California Division of Forestry, Department of Natural Resources.

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Rainfall sampling to estimate how much water falls on the mountain watersheds of the San Dimas Experimental Forest has had an interesting evolution. By continually refining measurement techniques and sampling methods, we have been able to make 21 raingages provide estimates more useful in hydrologic studies than those once provided by more than 300 gages.

Hydrologic studies of watershed management research demand the best possible estimates of rainfall. Starting in 1933 a network of 322 raingages was installed on the experimental forest. Such a large number was, of course, unwieldly to operate and maintain, but little was known about mountain rainfall: it was necessary to collect an abundance of data to establish the precipitation pattern. Then, this knowledge could be applied to increase the accuracy of our estimates and eventually to simplify the sampling procedure.

These objectives were successful[1/] and our first improvement came when the sampling network was reduced to 77 gages. The original system had used conventional vertical gages located every half mile on trails along 2,100-, 3,100-, 4,100-, and 5,100-foot contours. The improved system located one or more gages so as to sample facets of reasonably uniform aspect, slope, and elevation within each watershed. These gages were tilted and oriented so their receiving surface was parallel to the watershed slope they represented. The gages were still located on the contour trails but their placement was adjusted to their topographic environment, including screening from the wind.

This more operational arrangement of 77 gages instead of 322 was still costly in time and money. To effect further economies, available data were examined and we tested an idea that we might be able to select from many gages one gage in each watershed which would integrate watershed rainfall. If this were possible, these gages could be made recording and would supply rate and quantity data even more expeditiously than the extensive network. Accordingly, a so-called "minimum" raingage network was selected from the existing 77 gage system.

1/ Hamilton, E. L. 1954. Rainfall sampling on rugged terrain, U. S. Dept. Agr. Tech. Bul. 1096. 41 pp., illus.

This network included 21 gages, distributed to sample watershed rainfall both by area and by elevation. Preliminary comparisons of measurements from the 21-gage network and the accredited 77-gage network showed that their respective watershed rainfall averages agreed within 3 percent.

The preliminary analysis indicated enough promise to warrant further testing of the "minimum" network. It would be accepted as adequate if it estimated storm rainfall within either 5 percent or 0.25 inch for each elevation zone of each watershed 2 times out of 3. The average rainfall sampled by the existing gages at 2,100-, 2,600-, 3,100-, 4,100- and 5,100-feet elevation in any watershed would be taken as correct. The analysis was set up so that data could be processed for least squares regressions by automatic calculator and accurate standard errors of estimate could be obtained easily as well as equations relating rainfall by elevations to the appropriate watershed minimum network gage.

Analytical Sample

Rainfall data from the established tilted gage network were available for the 7-year period 1947-48 through 1953-54, totaling 116 storms. Many storms had been read as combinations of 2 or more, so 77 observations totaling about 151 inches of rain were available. A sample of 15 observations was drawn at random from the 77, 5 observations from each of 3 storm-size classes: from the less than 1 inch, 1 to 3 inches, and greater than 3 inches. This size-class stratification was to insure a good distribution of storm amounts in the sample.

Analytical Procedure

Watershed rainfall at a particular elevation for the sample storms was related to the catch of the gage proposed for that area and least squares equations were derived for these regressions. In several watersheds, the average of 2 gages was needed to determine properly the elevational rainfall. Standard errors of estimate were made using all of the available data. Results were so close to those derived from the sample that the tests were not carried to any length.

Results

Standard errors of estimate ranged from 0.060 inch to 0.214 inch, with 13 of the 23 values falling between 0.12 and 0.18 inch (table 1). Thus the analysis more than met the criterion of two-thirds of the data falling within 5 percent or 0.25 inch of a regression line relating the "minimum" gage values to their corresponding network averages.

Table 1.--Summary of least squares computations to test adequacy of minimum network rain gages

Watershed number	Minimum network gage	Standard error of estimate at elevation of --					Regression equation[1] y = a + bx	
		2,100'	2,600'	3,100'	4,100'	5,100'	a	b
		inches						
I	$\frac{\text{I-41 + I-8}}{2}$	--	--	0.156	--	--	-0.045	1.022
	1104	--	--	--	0.127	--	+0.074	0.952
	I-56	--	--	--	--	0.188	-0.034	0.987
II	I-42	--	--	.150	--	--	+0.025	1.031
	$\frac{\text{I-42 + I-32}}{2}$	--	--	--	.157	--	+0.004	0.965
	I-32	--	--	--	--	.162	+0.025	0.981
III	I-42	--	--	.199	--	--	-0.054	1.024
	I-31	--	--	--	.118	--	+0.016	1.024
	I-112	--	--	--	--	.101	-0.016	1.017
V	I-41	--	0.214	--	--	--	-0.076	1.046
	I-35	--	--	.105	--	--	+0.002	1.000
	I-31	--	--		.201	--	+0.082	0.968
VII	$\frac{\text{I-47 + I-50}}{2}$	0.147	--	--	--	--	+0.080	1.003
	I-47	--	.164	--	--	--	-0.089	1.068
VIII	I-13	.127	--	--	--	--	-0.046	1.049
	$\frac{\text{I-13 + I-52}}{2}$	--	.060	--	--	--	-0.002	1.002
	I-52	--	--	.098	--	--	-0.031	1.007
IX	I-13	.170	--	--	--	--	-0.046	1.019
	$\frac{\text{I-13 + I-2}}{2}$	--	.169	--	--	--	+0.041	0.959
	I-2	--	--	.143	--	--	-0.006	0.980
X	I-49	.155	--	--	--	--	-0.139	1.104
	$\frac{\text{I-49 + I-30}}{2}$	--	.184	--	--	--	+0.076	0.973
	I-30	--	--	.161	--	--	+0.032	1.024

1/ y = average rainfall by tilted gage network at a specified elevation in a watershed. x = rainfall at a minimum network gage for a specified elevation in a watershed.

Adequacy of Minimum Network for Watershed Average Rainfall

The minimum raingage network was compared with the tilted gage network to determine how well average watershed rainfall could be determined by the reduced number of gages. Data were compared for the 77 observations in the 7-year period.

Storms in the 1- to 3-inch and the greater than 3-inch size-classes produced most of the rain in the period. Two-thirds, and generally more, of the storm rainfalls in these classes deviated less than 5 percent from the watershed averages determined from the tilted gage network (tables 2 and 3). These are the storms of greatest importance in watershed management research. The smallest storms varied considerably by watersheds, but at least half of the storms were within 5 percent of the watershed average. In this class a difference of 0.05 inch might mean a deviation of 20 percent, and this small quantity could easily be classed as observational error. It was concluded, then, that the minimum gage network would permit suitable determinations of average watershed rainfall.

Table 2.--Number of storms by storm size class in which minimum rain gage network average differed from tilted rain gage network average by less or more than 5 percent

Period 1947-48 to 1953-54 inclusive

Watershed number	Storms less than 1 inch		Storms 1 to 3 inches		Storms more than 3 inches	
	Difference < 5 pct.	Difference > 5 pct.	Difference < 5 pct.	Difference > 5 pct.	Difference < 5 pct.	Difference > 5 pct.
I	15	16	22	14	7	3
II	16	15	25	11	8	2
III	18	13	22	14	10	0
V	17	14	27	9	9	1
VII	20	11	31	5	9	1
VIII	19	12	29	7	9	1
IX	20	11	29	7	10	0
X	21	10	31	5	10	0
All	22	9	29	7	9	1
No. storms in size class	31		36		10	
Rainfall in size class, inches	17		66		67	

Table 3.--Percent deviations of annual watershed rainfall averages determined by minimum raingage network from averages of tilted raingage network, by storm size classes

Watershed number	1947-48 to 1949-50	1950-51	1951-52	1952-53	1953-54
STORMS LESS THAN 1 INCH IN AMOUNT					
I	-1.3	+5.0	-1.0	+4.0	-20.0
II	-2.6	-0.5	0.0	+0.7	-11.2
III	-3.6	+2.6	-2.0	0.0	-19.7
V	-3.7	+3.3	-8.8	+6.8	-12.5
VII	+3.2	-0.1	-4.3	-3.9	+ 3.1
VIII	-0.9	+3.5	-1.9	-2.2	-35.8
IX	-0.9	+1.9	-6.3	-0.8	- 4.3
X	-2.4	+3.1	+4.2	-3.8	-15.7
All	-2.5	+1.5	-4.0	+0.7	-10.4
No. storms	18	3	3	4	2
Rainfall, inches	9	2	2	3	1
STORMS OF 1 TO 3 INCHES IN AMOUNT					
I	-0.2	-0.5	+0.3	+0.4	- 3.2
II	-0.6	+0.4	-1.6	+0.7	- 9.7
III	+0.8	0.0	-2.7	-5.0	- 0.8
V	0.0	+2.6	-1.0	-1.2	+ 1.0
VII	-0.4	+0.1	-5.2	-0.8	+ 0.9
VIII	+1.2	+1.0	-1.7	-1.9	+ 0.9
IX	+0.3	0.0	-0.2	-0.4	+ 0.8
X	-1.0	+3.0	-2.6	+1.4	+ 1.7
All	-1.4	+1.0	-2.2	-3.7	- 3.4
No. storms	14	7	7	8	1
Rainfall, inches	29	10	14	14	1

Table 3.--Continued

Watershed number	1947-48	1948-49 1/	1949-50	1950-51	1951-52	1952-53	1953-54	7-year period
STORMS GREATER THAN 3 INCHES IN AMOUNT								
I	--	+2.8	--	0	+3.1	0	+1.1	
II	--	+2.4	--	0	+1.7	0	+0.7	
III	--	+1.8	--	0	-1.6	0	-1.1	
V	--	-2.5	--	0	-0.7	0	-1.7	
VII	--	-0.2	--	0	-0.1	0	-3.4	
VIII	--	+1.5	--	0	+1.1	0	+0.4	
IX	--	-0.2	--	0	+1.4	0	0.0	
X	--	-0.4	--	0	+0.3	0	0.0	
All	--	-1.3	--	0	+0.2	0	+1.0	
No. storms	--	4	--	0	3	0	3	
Rainfall, inches	--	16	--	0	27	0	23	
ALL STORMS								
I	+2.6	-1.8	+1.3	+0.2	+0.8	+0.7	0.0	+0.8
II	+1.8	-1.8	-0.2	+1.1	+0.6	+0.8	-1.0	+0.2
III	-0.5	-0.5	-0.6	-0.6	-2.0	-4.0	-1.6	-2.7
V	-1.4	-0.8	-1.9	+2.8	-1.0	-0.2	-1.9	-1.0
VII	0.0	+1.4	-0.6	+0.8	-1.9	-2.5	+0.7	-1.2
VIII	+1.4	-0.8	+2.1	+1.4	+0.5	+0.1	-1.3	+0.2
IX	+1.2	-3.5	+1.8	+0.1	+0.6	+0.2	0.0	+0.2
X	-2.9	-1.6	+0.3	+3.2	-0.5	+0.4	+1.1	0.0
All	-0.6	-2.3	-1.8	+1.0	-0.7	-0.5	-0.3	-1.0
No. storms	11	15	10	10	13	12	6	77
Rainfall, inches	15	18	21	12	43	17	25	151

1/ Represents average of 3 years 1947-48 to 1949-50.

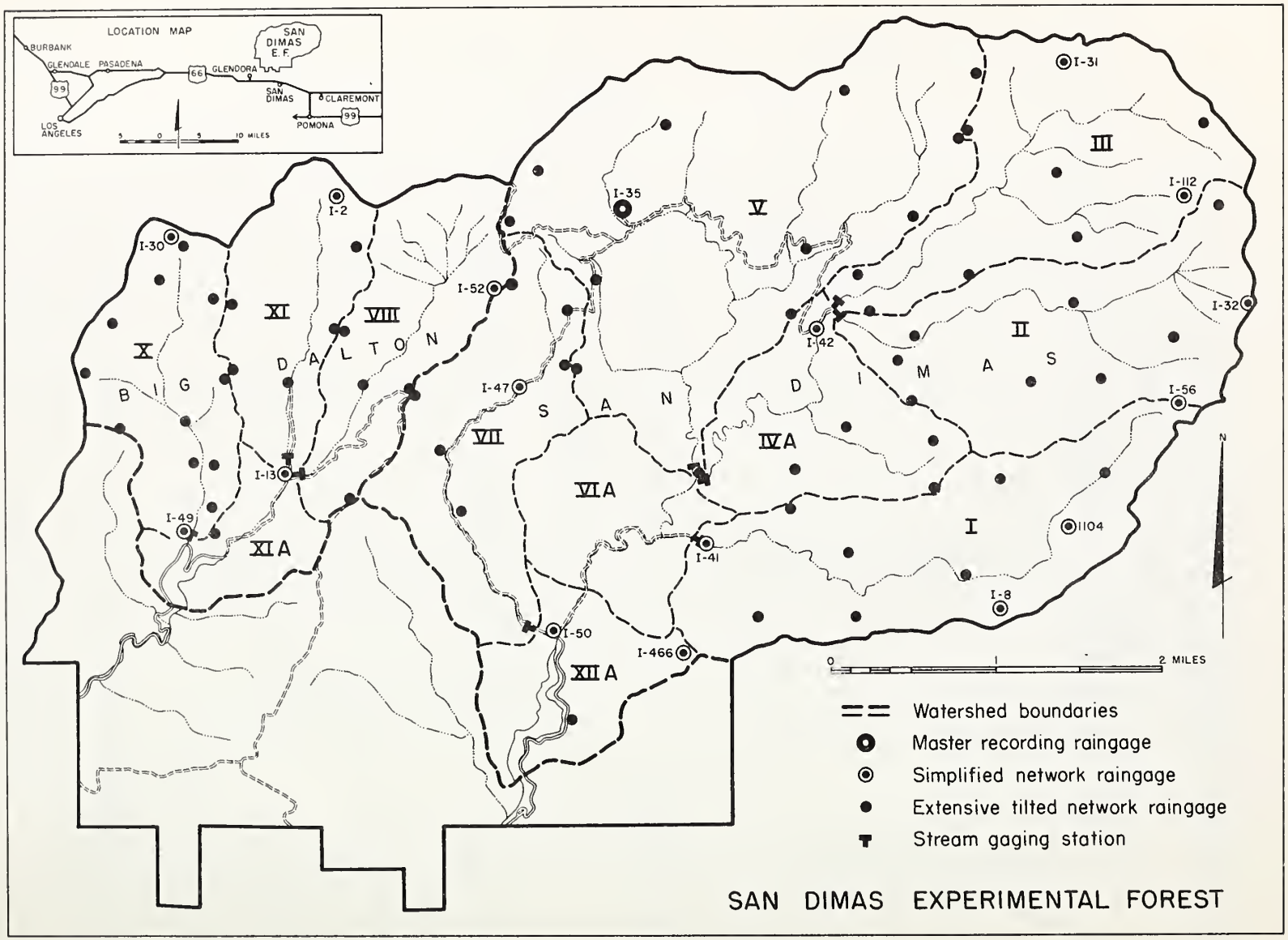

Figure 1 --Distribution of 17 gages superimposed on the 77 tilted gage network.

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